Improvement of HF RFID detection for small and misaligned tag

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***Abstract*—A design of a reader antenna is proposed to optimize HF RFID range detection in parallel and perpendicular configuration. The reader antenna has a surface of 500 cm^2, the tag corresponds to 0.7% of the reader surface. For passive RFID system, if the reader antenna does not provide the threshold energy to the tag, this one will not be detected. This is the case of the misalignment systems with great difference size antenna. Another problem limiting RFID detection is the different possible tag orientations. In perpendicular configuration, the detection is weak, the tag can only be detected above the edges of the antenna. These limits are minimized in this work by using a multiple loop antenna including resonators. Electrical model is developed to calculatethe equivalent mutual inductance of the system from the impedance matrix:the measured results confirm the simulated ones.The detection measurements validate the improvement.**

Keywords— RFID; coil; mutual inductance; detection

I. INTRODUCTION

RFID (Radio Frequency Identification) at LF (Low Frequency, 125 kHz) and HF (High Frequency, 13.56 MHz) is based on load modulation principle, thanks to inductive coupling effect between the reader and the tag coils. Optimizing mutual inductance depends on the distance between the reader and the tag but also on their respective shapes and spatial orientation [1][2][3][4]. As the size of the tag coil is usually small compared to the reader coil, the coupling effect is considered to be weak.

In the context of such near field communications, the structure of the reader coil can be modified in a multi-coils way [5][6][7] in RFID and in WPT (Wireless Power Transfer) applications [8][9]. Equivalent circuit of the systems is useful for detailed analysis [10] and the calculation of the mutual inductance [12][13] is a key parameter to improve the tag detection in RFID [14] and the efficiency in WPT system. In the literature, several proposed structures exhibit symmetric, and co-axial coils [9][10], but a few ones are applied to asymmetric structures with perpendicular and offset arrangement of the transmitting and receiving coils [8].

In this paper, a method to improve detection range for misaligned small tag is proposed. Reader antenna based on dual twisted loop antenna (three sub-coils) including resonators is used to optimize misalignment tag detection. Each juxtaposed coils of the multi-loop reader antenna are fed in out-phase current. The mutual coupling between the reader multi-coils and the tag depends on the mutual inductance; the corresponding electrical model is developed in theoretical study of this paper. Herein, we focus first on a “three sub-coils prototype” including resonator in each sub-coil.The optimization and maximization of the mutual impedance value is our figure of merit. The proposed structure is produced and validated by detection measurement in parallel and perpendicular configurations.

II. THERITICAL STUDY

HF RFID system is based on magnetic coupling. The generated magnetic field by the reader coil creates a current circulation in the tag coil, hence, the tag chip is loaded. The effect of the tag chip variation on the shown impedance of the reader is modeled by:

$$Z_{in} = Z_1 + \frac{\omega^2 M^2}{Z_2 + Z_T} \quad (1)$$

With Z_1, Z_2 and Z_T are respectively the impedance of the reader coil, tag coil and tag chip.

This is the principle of the load modulation. Then, to enhance tag detection, the mutual inductance should be increased.

To determinate theoretically the equivalent mutual inductance between the reader multiple coils including resonators and the tag, we use the electrical equivalent model in Fig. 1. Each coil is modeled by an inductor L_i with its serial resistance r_i. L_1, L_2 and L_3 are respectively the self-inductances of the sub-coils of the reader antenna. L_{r1}, L_{r2} and L_{r3} are the self-inductances of the resonators and L_T is the inductance of the tag coil. C_1, C_{r1}, C_{r2} and C_{r3} are the tuning capacitors at 13.56 MHz of the reader antenna and the resonators.

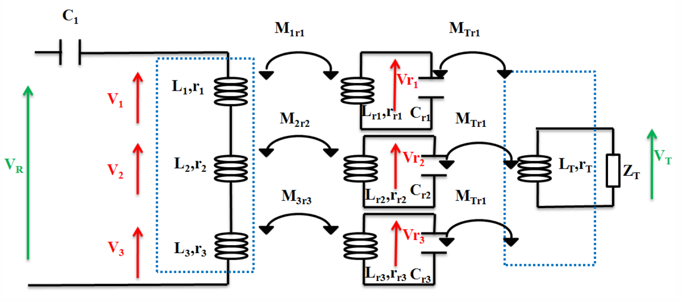


Fig.1.Electrical model of the proposed antenna

The voltages V_1, V_2 and V_3 in the circuit satisfy the following relations (1), with $M_{ij}=M_{ji}$ being the mutual inductances between coils of the reader antenna (1<i,j<3)), M_{1r1}, M_{2r2} and M_{1r3} are the mutual inductances between the resonator and the corresponding sub coil. M2r1, M2r2 and M2r3 are the mutual coupling between resonators and the tag coil.

As the multi-coils antenna is defined by three serial inductances, the voltage can be written in the harmonic regime (at frequency $\omega = 2\pi f$) as:

$$
\begin{aligned}
V_1 &= (r_1 + j\omega(L_1 + M_{12} + M_{13}))I_R + j\omega M_{1T} I_T \\
V_2 &= (r_2 + j\omega(L_2 + + M_{21} + M_{23}))I_R + j\omega M_{2T} I_T \\
V_3 &= (r_3 + j\omega(L_3 + M_{32} + M_{31}))I_R + j\omega M_{3T} I_T
\end{aligned}
\quad (2)
$$

Where M_{13} and M_{31} are negligible to M_{12} and M_{32}

The voltage V_R is the sum of the different voltages:

$$
V_R = \begin{pmatrix} r_1 + r_2 + r_3 + \\ j\omega(L_1 + L_2 + L_3 + 2*M_{12} + 2*M_{23}) \end{pmatrix} I_R + j\omega(M_{1T} + M_{2T} + M_{3T})I_T \quad (3)
$$

The mutual inductance between the reader multiple coils and the tag is then equal to:

$$
M_{RT} = M_{1T} + M_{2T} + M_{3T} \quad (4)
$$

In presence of resonators the voltages becomes:

$$
\begin{aligned}
V_1 &= \left(r_1 + \frac{\omega^2 (M_{1r1})^2}{\alpha_{r1}} + j\omega(L_1 + M_{12})\right) I_R + \left(j\omega M_{1T} + \frac{\omega^2 M_{1r1} M_{Tr1}}{\alpha_{r1}}\right) I_T \\
V_2 &= \left(r_2 + \frac{\omega^2 (M_{2r2})^2}{\alpha_{r2}} + j\omega(L_2 + + M_{21} + M_{23})\right) I_R + \left(j\omega M_{2T} + \frac{\omega^2 M_{2r2} M_{Tr2}}{\alpha_{r2}}\right) I_T \\
V_3 &= \left(r_3 + \frac{\omega^2 (M_{2r3})^2}{\alpha_{r3}} + j\omega(L_3 + M_{32})\right) I_R + \left(j\omega M_{3T} + \frac{\omega^2 M_{3r3} M_{Tr3}}{\alpha_{r3}}\right) I_T
\end{aligned}
\quad (5)
$$

Where: $\alpha_{ri} = \frac{j}{\omega C_{ri}} - (j\omega L_{ri} + r_{ri})$ $(1 \le i \le 3)$.

The equivalent mutual impedance between the tag and the reader including resonators can be expressed by:

$$
\begin{aligned}
Z_{RT} &= j\omega M_{1T} + \frac{\omega^2 M_{1r1} M_{Tr1}}{\alpha_{r1}} \\
&+ j\omega M_{2T} + \frac{\omega^2 M_{2r2} M_{Tr2}}{\alpha_{r2}} \\
&+ j\omega M_{3T} + \frac{\omega^2 M_{3r3} M_{Tr3}}{\alpha_{r3}}
\end{aligned}
\quad (6)
$$

Finally, the equivalent mutual inductance between the reader and the tag is the imaginary part of the Z_{RT}:

$$
\begin{aligned}
M_{RT} &= j\omega M_{1T} + \omega^2 M_{1r1} M_{Tr1} \gamma_{r1} \\
&+ j\omega M_{2T} + \omega^2 M_{2r2} M_{Tr2} \gamma_{r2} \\
&+ j\omega M_{3T} + \omega^2 M_{3r3} M_{Tr3} \gamma_{r3}
\end{aligned}
\quad (7)
$$

With

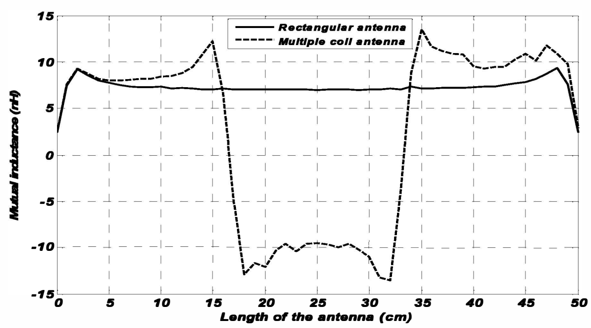
$$
\gamma_{ri} = \frac{\frac{1}{C_{ri}\,\omega} - \omega L_{ri}}{\left(\frac{1}{C_{ri}\,\omega} - \omega L_{ri}\right)^2 + r_{ri}}
$$

The equations are used in the following sections to evaluate the improvement of the mutual inductance with the proposed design.

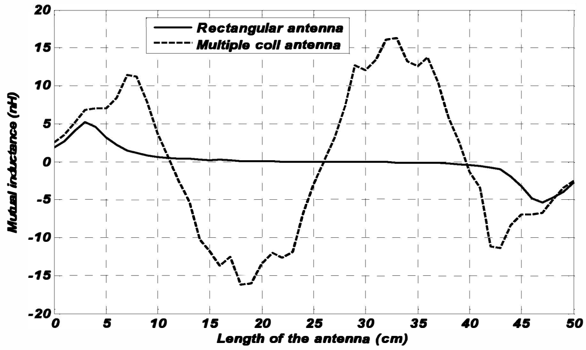
III. SIMULTAION AND MEASURES RESULTS

A. Validation of the concept of multiple coils

For two reader antenna: rectangular one of 50*10 cm^2 and a multi-coils (three sub-coils of 10*16.6 cm^2) , and a tag of 1.2 cm radius coil, the concept of the multi-coils is validated by evaluating improvement of mutual inductance in equations (4 and 7) (Fig. 2).



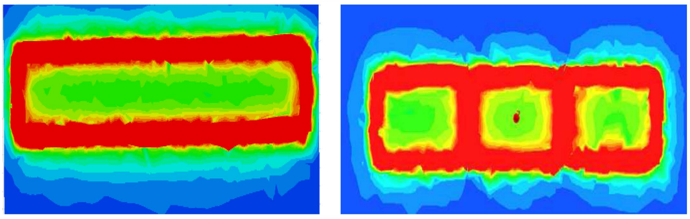
(a)



(b)

Fig. 2:Mutual inductance for rectangular and multiple coils antenna in parallel (a) and perpendicular configuration (b)

The proposed design permits the improvement of mutual inductance in both parallel and perpendicular configurations. The maxima are above the transition zones between each two sub-coils for perpendicular configuration with an improvement of 16 nH compared to the rectangular antenna. In parallel configuration the maximum of mutual inductance is seen at the second sub-coil (improvement of the mutual inductance from 20 nH) The improvement of the mutual inductance is due to the modified distribution of the magnetic field (Fig. 3).



a b

Fig. 3. Generated magnetic field for rectangular and multiple coils antenna

B. *Proposed prototype including resonator*

Thegenerated magnetic field by the proposed design has minimum zones of the magnetic field. The addition of a resonator at the surface of each sub-coil of the reader antenna concentrates and modifies the distribution of the generated magnetic field, as it can be shown in (Fig. 4).

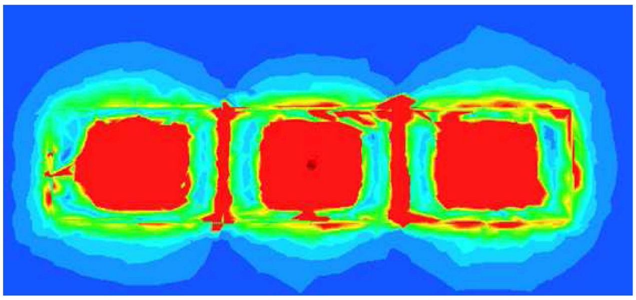
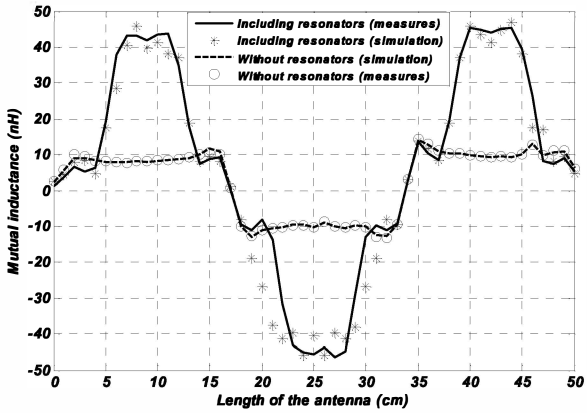


Fig. 4. Generated magnetic field with resonators

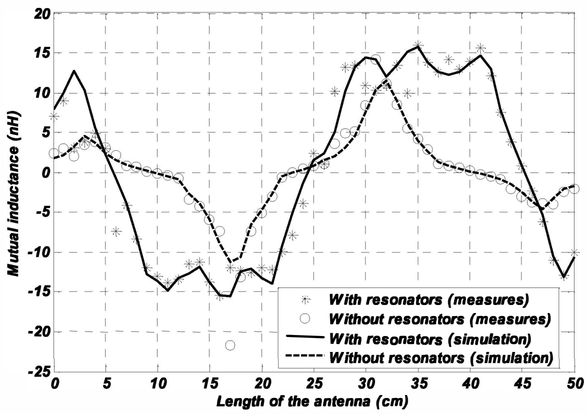
In equation 7 the mutual inductance is depending on the mutual inductances between the reader coils and the resonators, the tag and the resonators, but also on the electrical parameters of the resonators. In this study, the resonators have the same electrical properties, their impedance are equal to 1.5+j124. Each one of the resonators is including at the surface one sub-coil.

The prototype is produced and measured. The inductances of the antennas are 1.05 µH and L1= 1.46 µH respectively for rectangular and multi-coils antenna. The resonators are inserted at the center of each sub-coil. "Fig. 5" reports the simulated and measured results in two cases: with and without resonators. For a distance 1 cm, the calculated equivalent mutual inductance has comparable values to the measures.

For lateral misalignments, the addition of the resonators increased, in parallel configuration, the equivalent mutual inductance by 30 nH (from 13 nH to 43 nH) and above each sub coil. However, the equivalent mutual inductance presents three peaks corresponding at the surface of the resonators. In perpendicular configuration; the mutual inductance is improved by added resonators, from 8 nH and 5 nH respectively at the edges of the antenna and the center of the sub-coils (edges of resonators).



a



b

Fig. 5. Equivalent mutual inductance with and without resonators in parallel and perpendicular configuration

IV. EXPERIMENTAL VALIDATION

An experimental test of increasing detection volume and surface with adding resonator was made using a RFID reader from Ib Technologies. The principle of adding resonator on the co-planar surface of the reader coil was applied. The detection of parallel and perpendicular tag was evaluated for lateral misalignment and different distances between the tag and the reader antenna (Fig. 6).

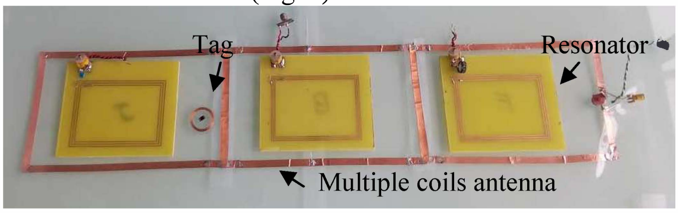
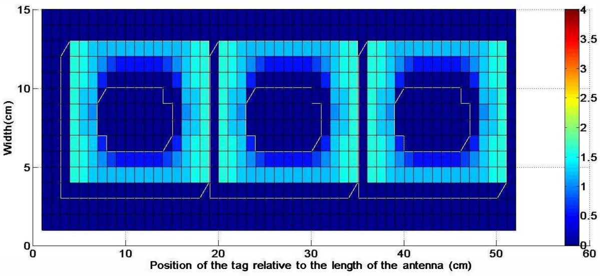


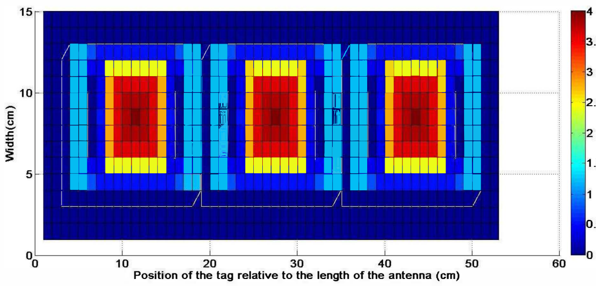
Fig. 6 proposed multiple coil antenna including resonators

The result of tag detection in parallel and perpendicular configurations without resonators (a, c), with resonators (b, d) are reported in Fig.7. The (X, Y) axes correspond respectively to a lateral misalignment according to the length and the width of the reader antenna, the color scale defined the distance of detection.

For resonator with size corresponding to 27% of the sub-coil surface, both the volume and the surface of detection for parallel and perpendicular configuration are increased (table I). The surface of the reader was increased by18% (From 70 % without resonators to 88% with resonators), and 29 % (From 16 % without resonators to 45 % with resonators) respectively for parallel and perpendicular configuration, since a new detection zones appears above the resonators. However the maximal distances of detection correspond to the center of the resonator in parallel configuration (4 cm) and to the edges of resonators and the sub-coils in the case of perpendicular configuration (1.3 cm)



a



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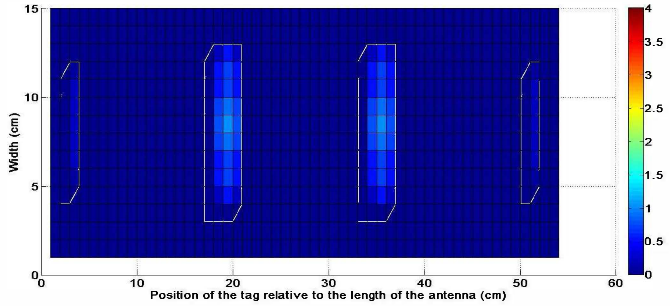
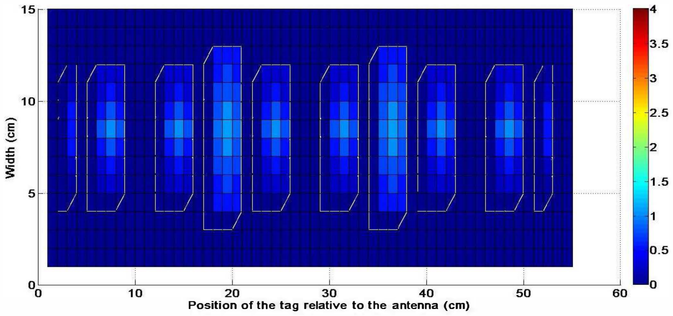


c



d

Fig. 7. Detection results in: parallel configuration with (b) and without (a) resonatorsand perpendicular configuration with (d) and without (c) resonators

The RFID detection results exhibit clearly that new detection zones appear with the addition of the resonator in the parallel and perpendicular orientations. This principle, using inductive coupling, can therefore be applied to HF and LF RFID applications to detect small tags in comparison with the global studied volume. For larger radii of readers coil, several resonators, weakly coupled to each other, can be added in different places on the reader surface therefore increasing the volume of detection.

V. Conclusion

The improvement of HF RFID system performances, such as surface and volume of tag detection, was obtained by association of multi-coil reader antenna including resonators. The improvement of equivalent mutual inductance was achieved thanks to the addition of a co-planar resonators.

The proposed multi- loop antenna, based on the changing phase currents between juxtapose coils, is fruitful for detection in both parallel and perpendicular orientation of the tag compared to the conventional loop but the distance and the surface of detection are not optimized. The added resonator at the surface of the sub coils of the reader antenna permits the improvement of detection.

Analytical formula for equivalent mutual inductance of the system is developed using electrical model of the structure, constituted of multi-coils reader antenna including resonators and tag. Simulations of the calculated equivalent mutual inductance with HFSS and comparisons with VNA measurementsare also performed.

In perspectives, the same principle will be also applied in wireless power transmission (WPT) to maximize the power transfer and the energy efficiency at the receiver and we will realize an optimized prototype with multiple resonating coils.

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